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WIND-TUNNEL TESTS OF A DUAL-ROTATING PROPELLER HAVING ONE COMPONENT LOCKED OR WINDMILLING

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Langley Memorial Aeronautical Laboratory
Langley Field, Va.

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ADVANCE RESTRICTED REPORT

WIND-TUNNEL TESTS OF A DUAL-ROTATING PROPELLER HAVING ONE COMPONENT LOCKED OR WINDMILLING

By Walter A. Bartlett, Jr.

SUMMARY

The effect on the propulsive efficiency of locking or windmilling one propeller of a six-blade dual-rotating-propeller installation was determined in the Langley propeller-research tunnel. Tests were made of both pusher and tractor configurations, with the unpowered propeller both leading and following the powered propeller, which was set at a blade angle of 40°.

The maximum propulsive efficiency of the powered propeller in combination with the locked or windmilling propeller was, in all cases, lower than that of the powered propeller operating alone.

The locked propeller gave greater maximum propulsive efficiencies when used as a contravane to remove rotational energy from the slipstream than when used as a means for imparting initial twist to the air. The windmilling propeller, however, was equally efficient both leading and following the driven propeller.

In the tractor installation, smallest losses in maximum propulsive efficiency were obtained when the unpowered following propeller was locked at a blade angle of 90° and when the unpowered leading propeller was allowed to windmill at a blade angle of 45°. In the pusher installation, equal losses in maximum propulsive efficiency were obtained when the unpowered following propeller was either locked at 90° or windmilling at 55°, but the unpowered leading propeller gave smallest losses when windmilling at 55°.

INTRODUCTION

In the event of engine failure in multiengine airplanes fitted with single-rotating propellers, the unpowered propeller is usually feathered in order to reduce the drag. For a dual-rotating propeller, it was desired to determine whether the feathered position is the optimum setting for the blades of an unpowered component. Tests of a six-blade dual-rotating propeller have therefore been conducted in the Langley propeller-research tunnel to determine the effect of a windmilling or locked component upon the aerodynamic characteristics of the complete propeller installation.

Tests of the propeller in both pusher and tractor configurations were conducted with the unpowered component both leading and following the powered component. The blade angle of the powered propeller was held at 40° and the blade angle of the unpowered propeller varied from 25° to 100°. This variation depended upon whether the installation was tractor or pusher and whether the unpowered component was windmilling or locked.

Because of the limitations in tunnel airspeed (100 mph) and propeller rotational speed (450 rpm), the Reynolds number and the propeller tip speed were appreciably lower than those normally encountered in flight. The maximum Reynolds number at the 0.75-radius station was of the order of 1,000,000, and the highest tip speed was approximately 240 feet per second. Reference 1 indicates that the effects of Reynolds number and tip speed are not critical within the range of the tests.

APPARATUS

The test setup was that used in previous propeller tests in the Langley propeller-research tunnel and is described in reference 2. Outline dimensions of the streamline nacelle are presented in figure 1, and photographs of the setup with a dual-rotating propeller installed as a tractor and as a pusher propeller are given in figure 2. The propeller blades used were the Hamilton Standard 3155-6 (right-hand) and 3156-6 (left-hand). The geometric characteristics of the blade are

given in figure 3. The front (right-hand) propeller disk was separated from the rear (left-hand) propeller disk by approximately 10 inches.

RESULTS AND DISCUSSION

The results are presented in the form of dimensionless coefficients, which are defined as follows:

C_T thrust coefficient $\left(\frac{T}{\rho n^2 D^4}\right)$

C_P power coefficient $\left(\frac{P}{\rho n^3 D^5}\right)$

V/nD propeller advance ratio

η propulsive efficiency $\left(\frac{C_T}{C_P}\frac{V}{nD}\right)$

where

T actual thrust of powered propeller minus drag of unpowered propeller and slipstream drag of nacelle, pounds

P power absorbed by propeller, foot-pounds per second

V airspeed, feet per second

n propeller rotational speed, rps

D propeller diameter, feet

ρ mass density of air, slugs per cubic foot

Also,

R propeller radius, feet

β blade angle at 0.75R, degrees

Subscripts:

F, R front and rear propellers, respectively

The results obtained for the various combinations of a powered component with a locked or windmilling component are compared with the characteristics of three-blade single-rotating propellers. The aerodynamic characteristics of the three-blade tractor or pusher propeller operating in either the front or the rear hub are presented in figure 4. Test points included in figure 4(a) indicate the experimental accuracy of the tests. The increase of approximately 1 percent in maximum propulsive efficiency when the three-blade propeller was operating in the rear hub over the efficiency when the propeller was operating in the front hub is within the experimental accuracy of the tests and hence cannot be ascribed to difference in shank losses.

Test results obtained with one component of the dual-rotating propeller operating and the other component locked either following or leading the operating component are presented in figure 5. These data, when compared with those in figure 4, show that the drag of the locked propeller at all blade angles tested more than offset any increase in thrust due to contravane action. The addition of the 90° locked propeller following or leading the driven tractor propeller lowered the maximum propulsive efficiency of the three-blade propeller 3 and 8 percent, respectively; and the addition of the 90° locked propeller following or leading the powered pusher propeller lowered the maximum propulsive efficiency 4 and 6 percent, respectively. The data show that smaller efficiency losses resulted when the locked propeller was installed as a contravane to remove the rotational energy from the slipstream than when used as a means for imparting initial twist to the air.

For both tractor and pusher configurations, when the unpowered propeller was allowed to windmill either following or leading the powered propeller, the maximum propulsive efficiency was found to be essentially independent of the location of the windmilling component for blade-angle settings from 40° to 55°. (See fig. 6.) The maximum propulsive efficiency of the tractor installation with the windmilling component following or leading the driven component was lower than that of the reference propeller by 6 percent and 7 percent, respectively; corresponding differences for the pusher installation were of the order of

4 percent. Very little friction opposed the windmilling propeller, and results indicated that the value of V/nD at which the propeller windmilled was independent of the rotational speed of the driven propeller, the forward or rearward location of the windmilling component in either the tractor or the pusher installation, and the operation with or without the driven propeller.

Aerodynamic characteristics are presented in figure 7 for the three-blade propeller operating alone and in optimum combination with the locked or windmilling component, both following and leading the driven component. For the tractor installation, with the unpowered propeller following the driven propeller, the beneficial contravane action of the rear propeller was greatest when locked at 90°. When the unpowered propeller led the powered propeller, the maximum efficiency was greatest for the combination with the windmilling propeller set at a blade angle of 45°. For the pusher installation, with the unpowered propeller following the powered propeller, the maximum propulsive efficiencies of the combinations with the locked propeller at a blade angle of 90° and with the windmilling propeller at a blade angle of 55° were of the order of 80 percent. When the unpowered propeller led the driven propeller, highest efficiencies were obtained with the windmilling component at a blade angle of 55°.

SUMMARY OF RESULTS

Wind-tunnel tests of a six-blade dual-rotating-propeller installation with the operating propeller set at a blade angle of 40° and with the inoperative propeller locked or windmilling indicated the following conclusions:

1. In all cases, the maximum propulsive efficiency with the locked or windmilling component was lower than that obtained with the three-blade propeller operating alone.

2. The locked propeller was most efficient when used as a contravane to remove rotational energy from the slipstream.

3. For blade-angle settings from 40° to 55°, the windmilling propeller was almost equally efficient both following and leading the powered propeller.

4. In the tractor-propeller installation, smallest losses in maximum efficiency were obtained when the inoperative following propeller was locked at a blade angle of 90° and when the inoperative leading propeller was allowed to windmill at a blade angle of 45°.

5. In the pusher-propeller installation, equal losses in maximum propulsive efficiency were obtained with the following propeller locked at a blade angle of 90° or windmilling at a blade angle of 55°, but the inoperative leading propeller gave smallest losses when windmilling at 55°.

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REFERENCES

1. Biermann, David, and Gray, W. H.: Wind-Tunnel Tests of Eight-Blade Single- and Dual-Rotating Propellers in the Tractor Position. NACA ARR, Nov. 1941.

2. Biermann, David, and Hartman, Edwin P.: Wind-Tunnel Tests of Four- and Six-Blade Single- and Dual-Rotating Tractor Propellers. NACA Rep. No. 747, 1942.

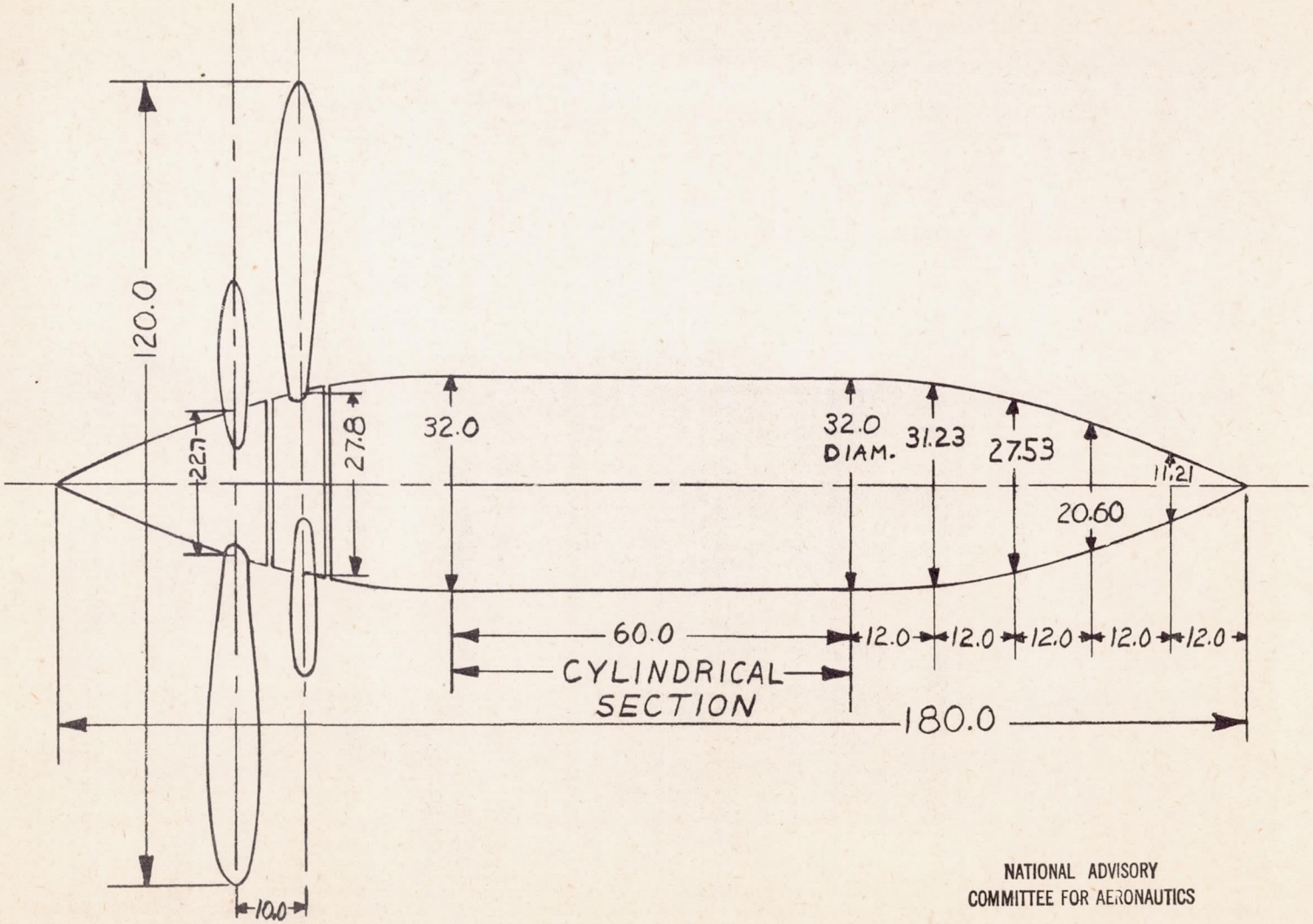
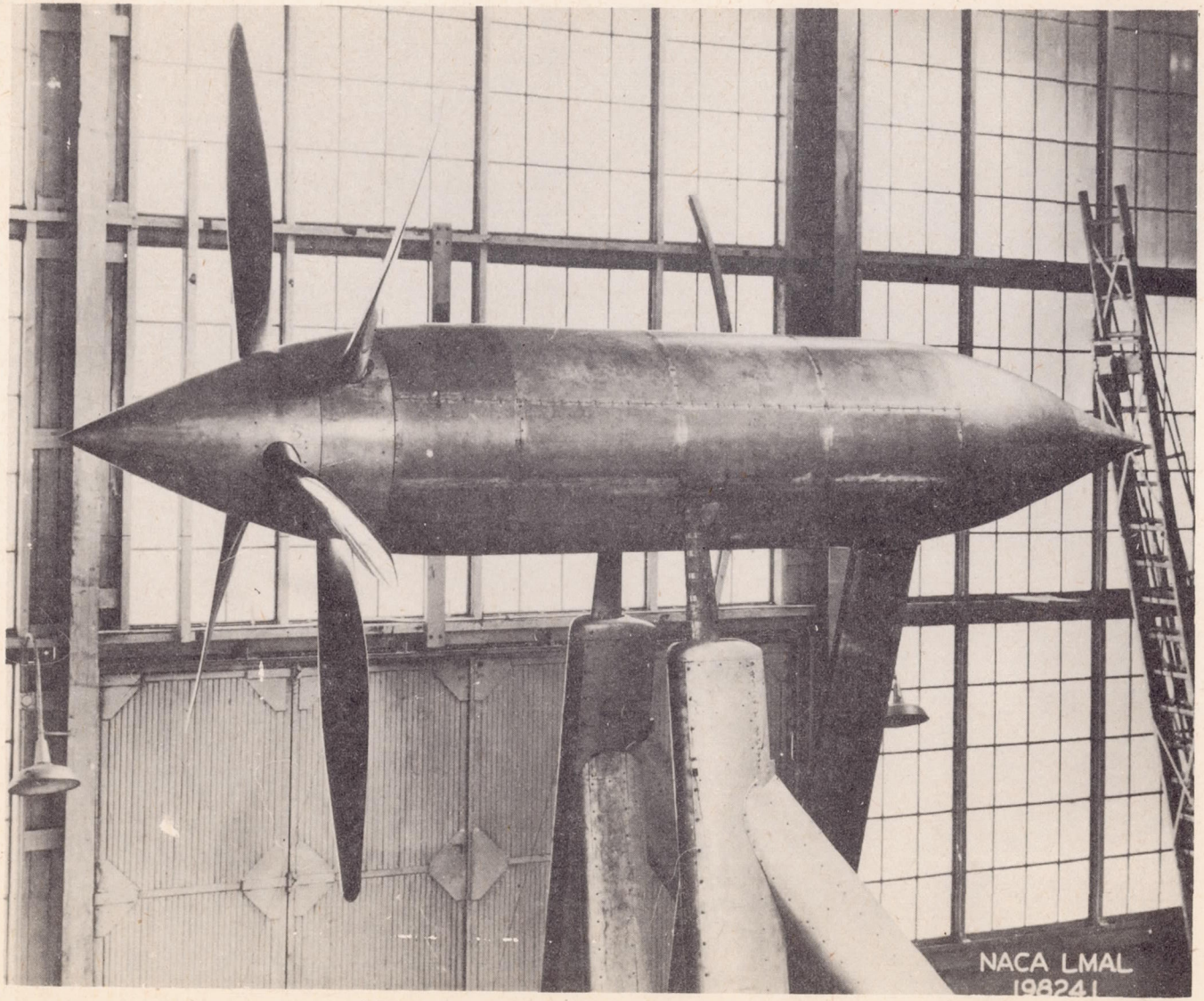
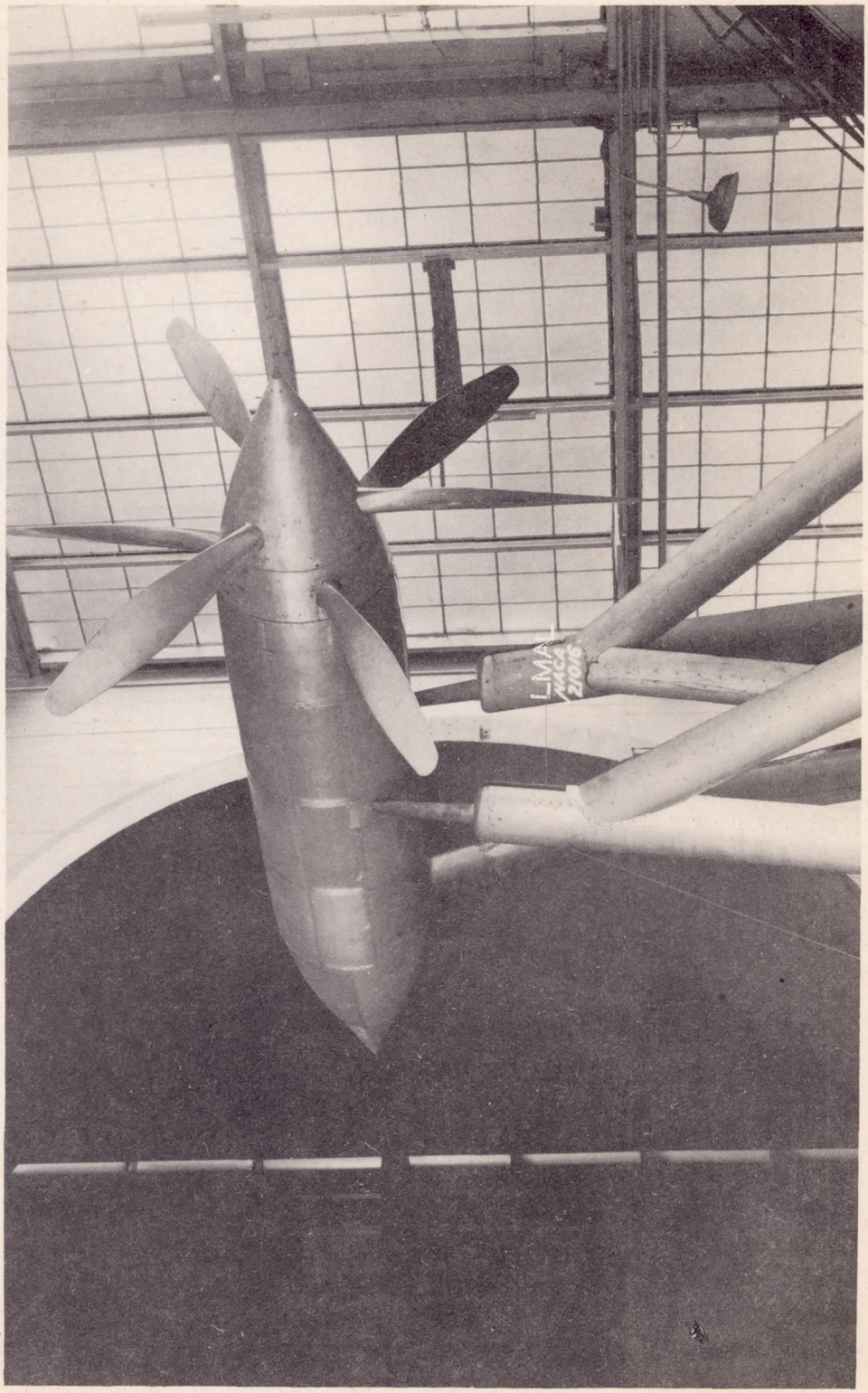


Figure 1.- Arrangement and dimensional details of the nacelle.
All dimensions are in inches.



(a) Tractor-propeller installation.

Figure 2.- Propeller and nacelle mounted in test section of Langley propeller-research tunnel.



(b) Pusher-propeller installation.

Figure 2.- Concluded.

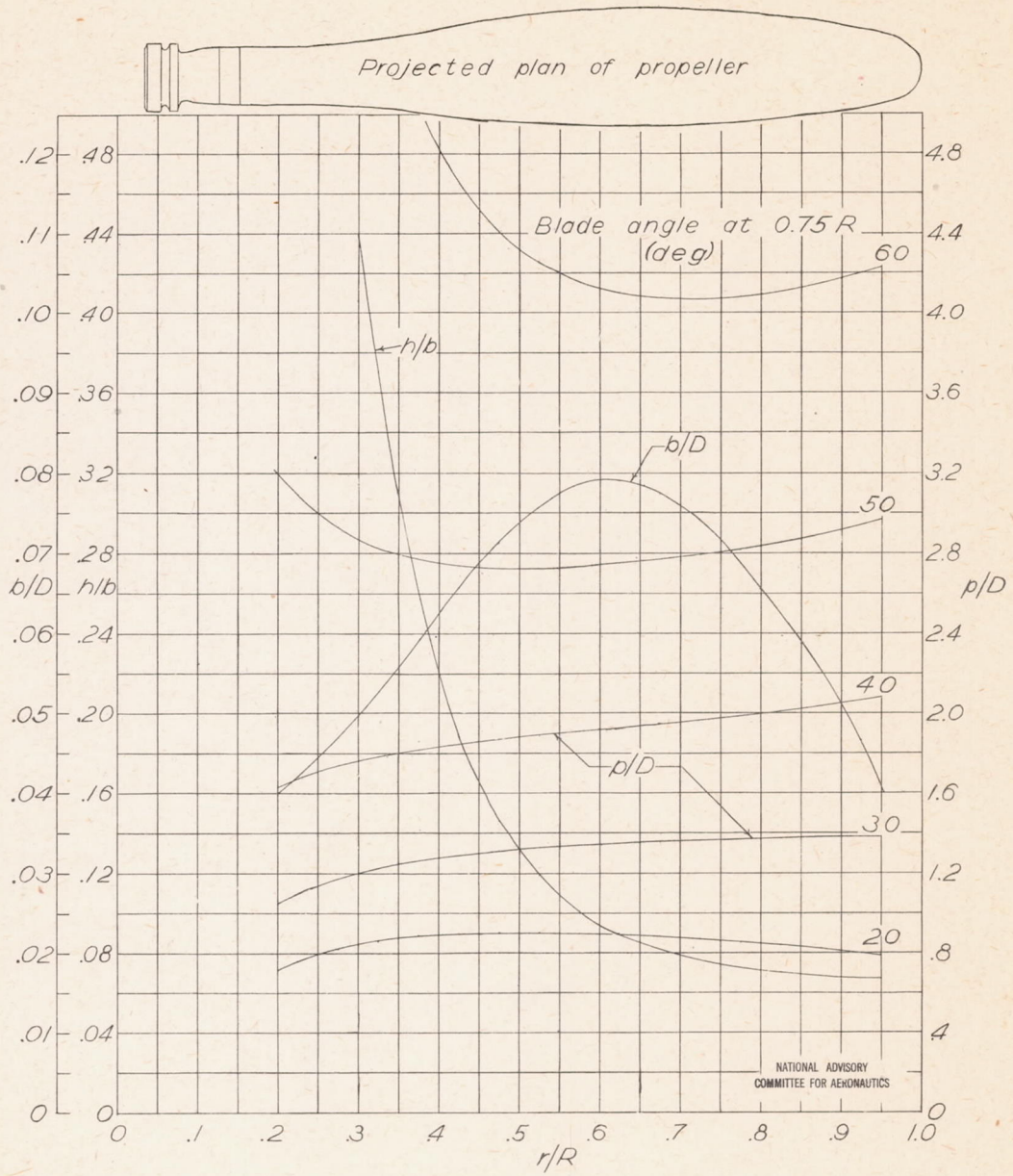
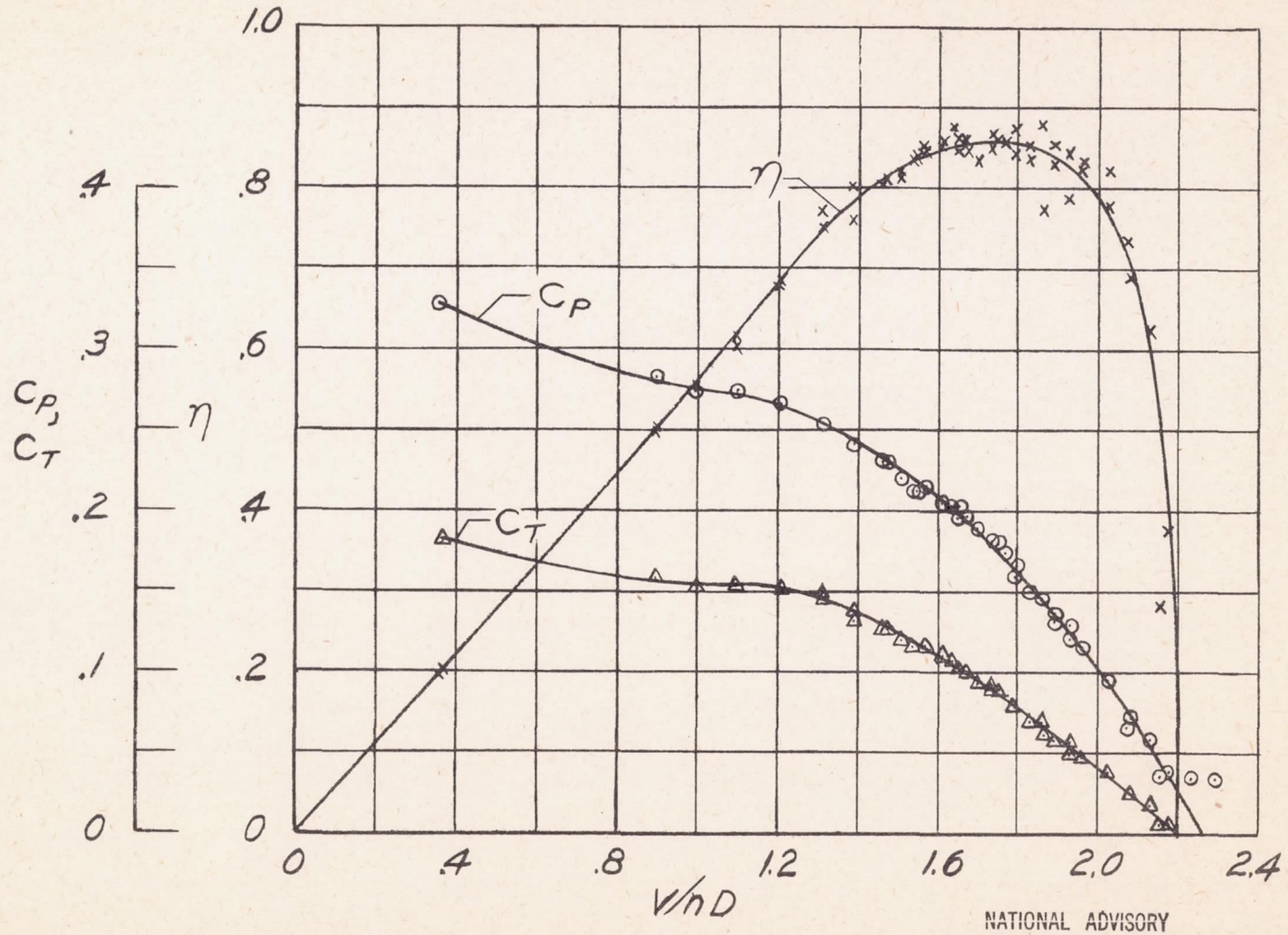
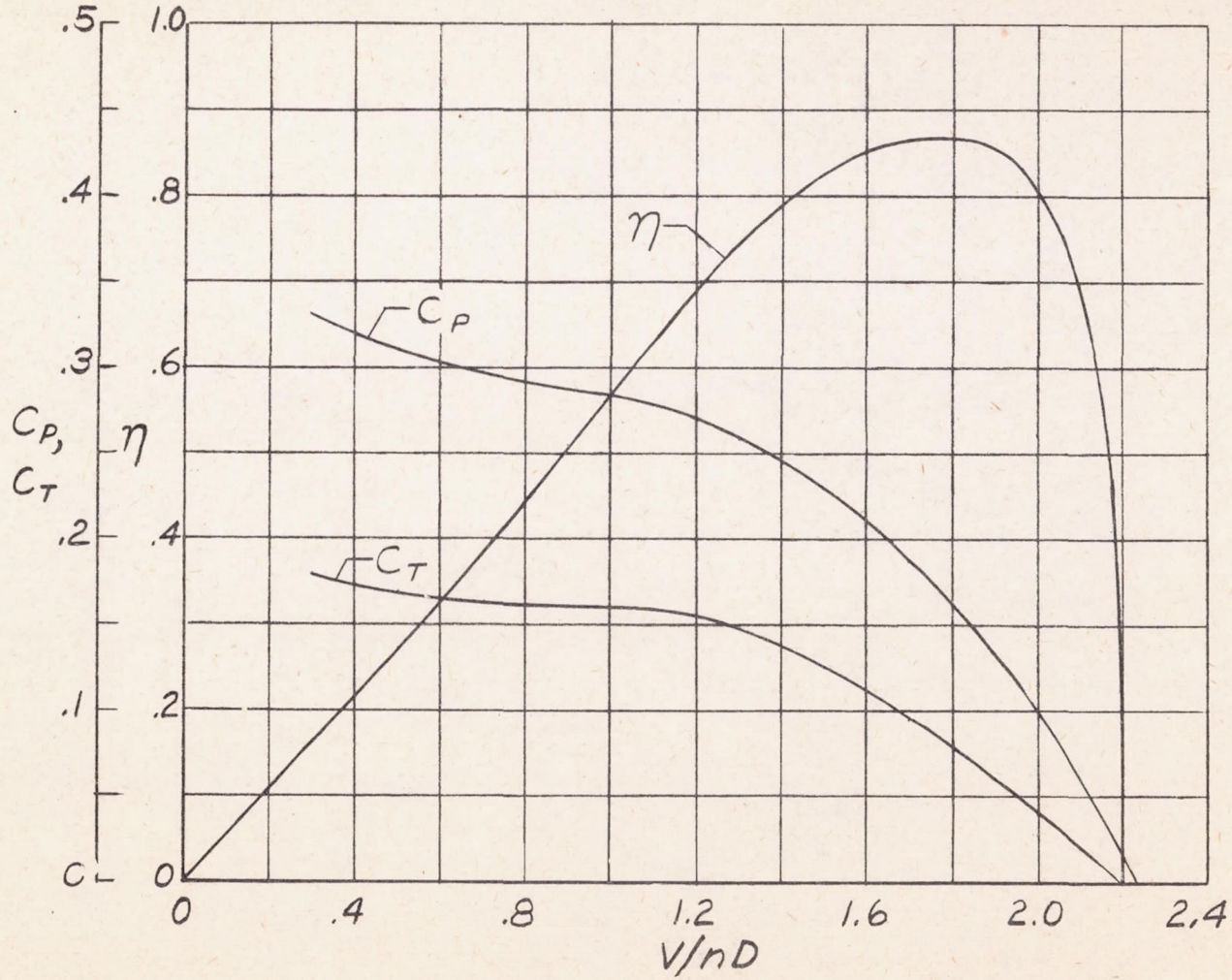


Figure 3. – Plan-form and blade-form curves for Hamilton Standard propellers 3155-6 (right hand) and 3156-6 (left hand). D, diameter; R, radius to tip; r, station radius; b, section chord; h, section thickness; p, geometric pitch.



(a) Tractor propeller in front hub.

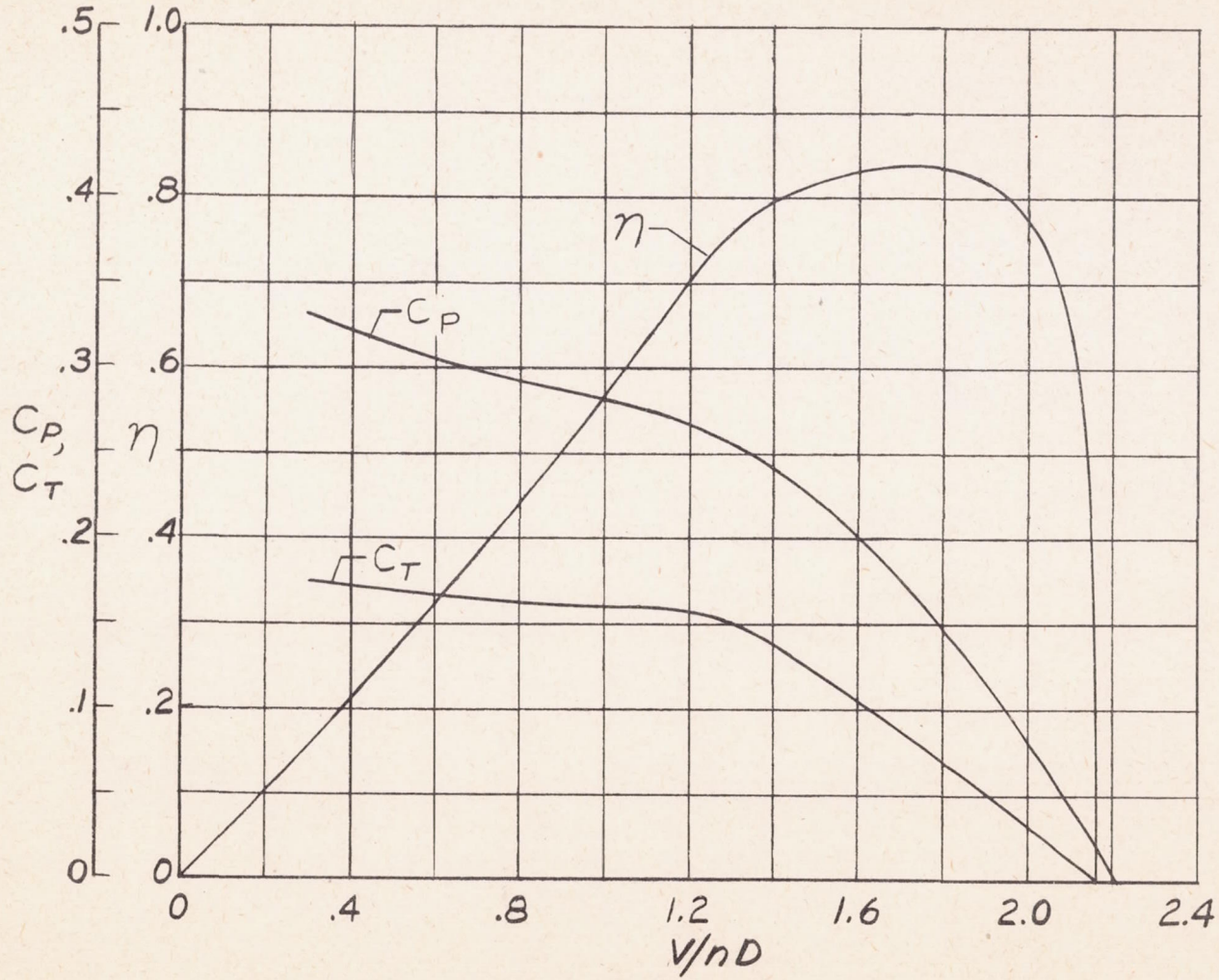
Figure 4.- Aerodynamic characteristics of the three-blade propeller. $\beta = 40^{\circ}$.



(b) Tractor propeller in rear hub.

Figure 4.- Continued.

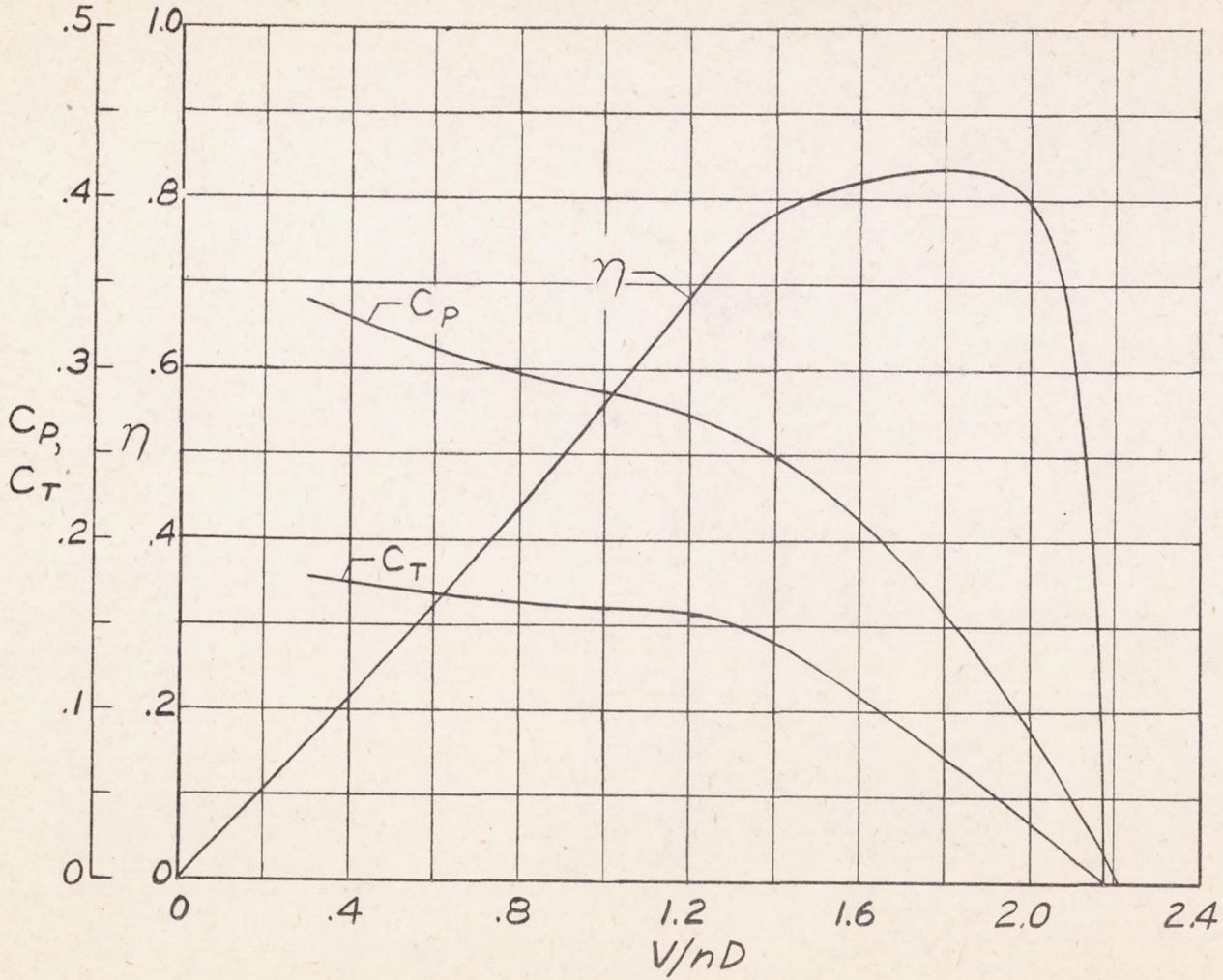
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(c) Pusher propeller in front hub.

Figure 4.- Continued.

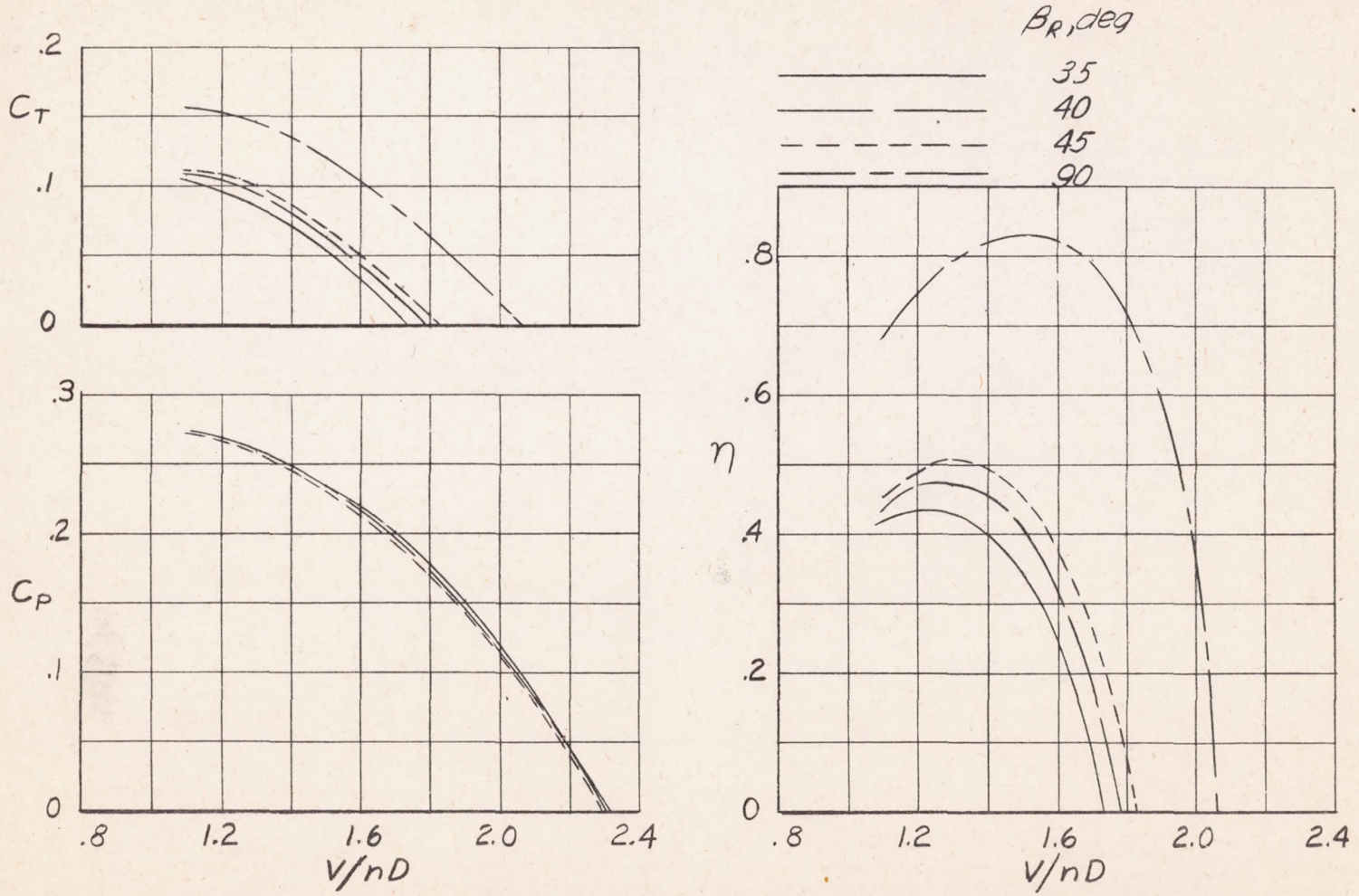
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(d) Pusher propeller in rear hub.

Figure 4.- Concluded.

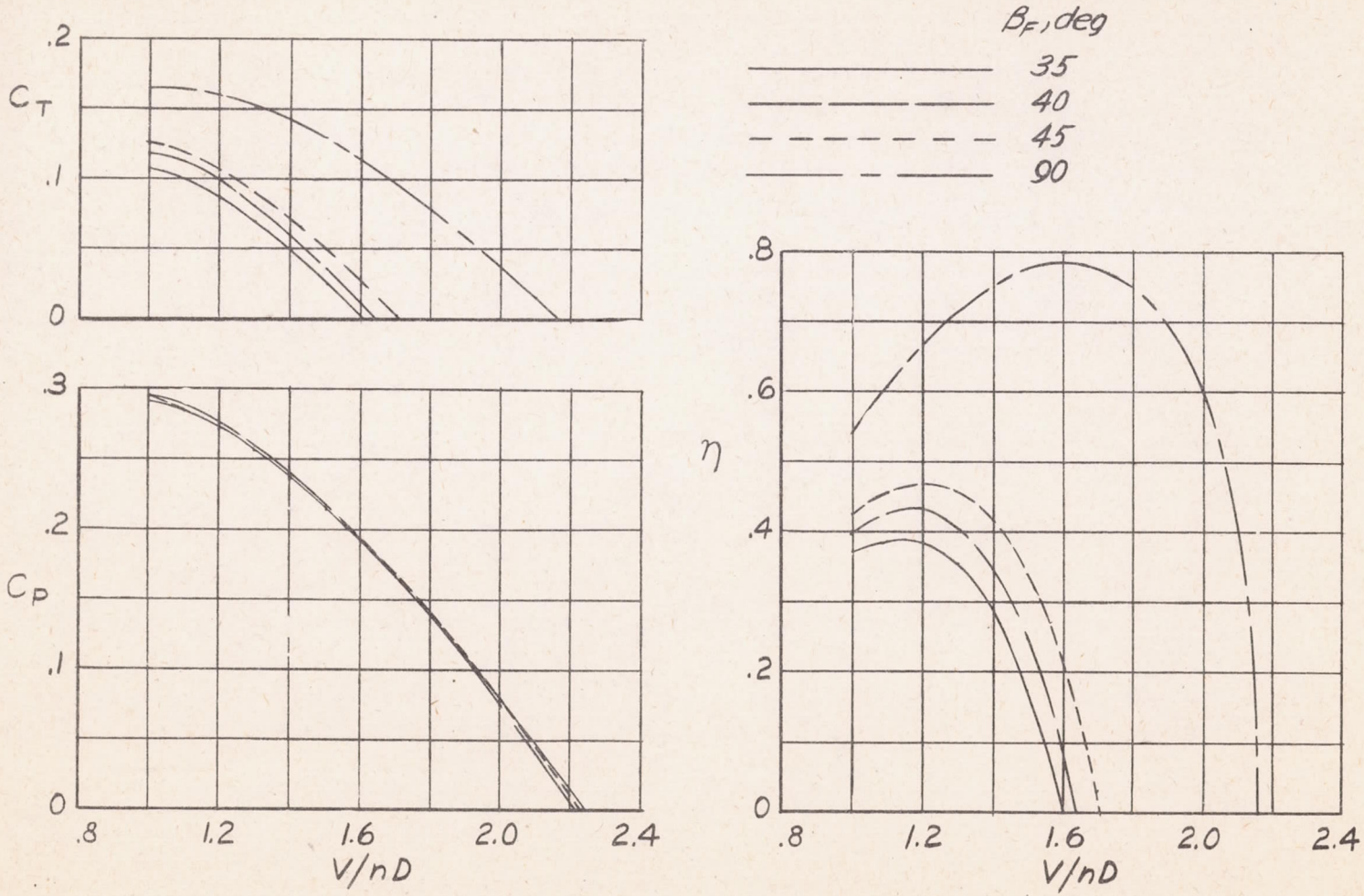
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(a) Tractor propeller; $\beta_F = 40^\circ$; rear propeller locked.

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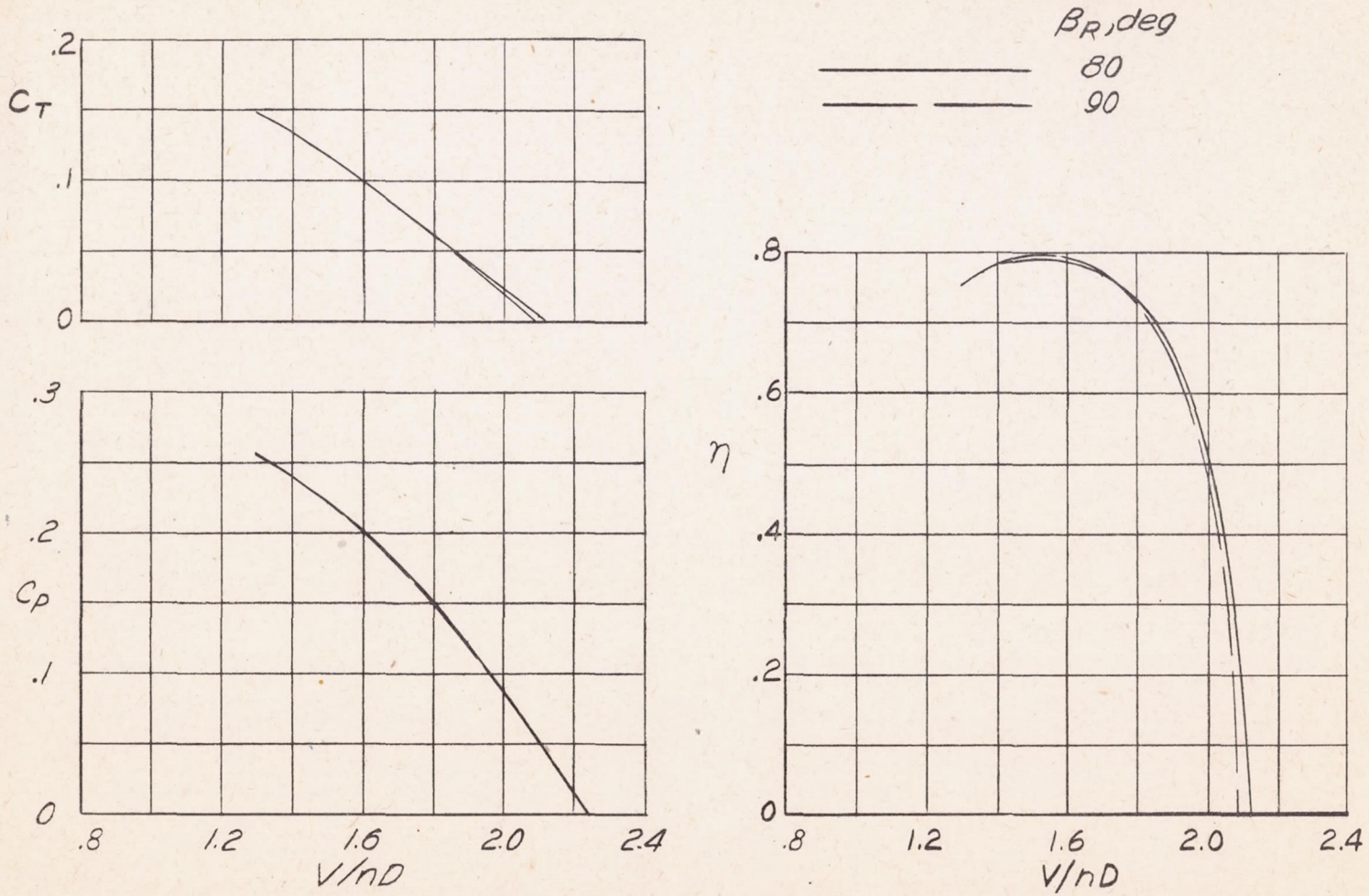
Figure 5.- Aerodynamic characteristics of the three-blade propeller operating in conjunction with the locked propeller.



(b) Tractor propeller; $\beta_R = 40^\circ$; front propeller locked.

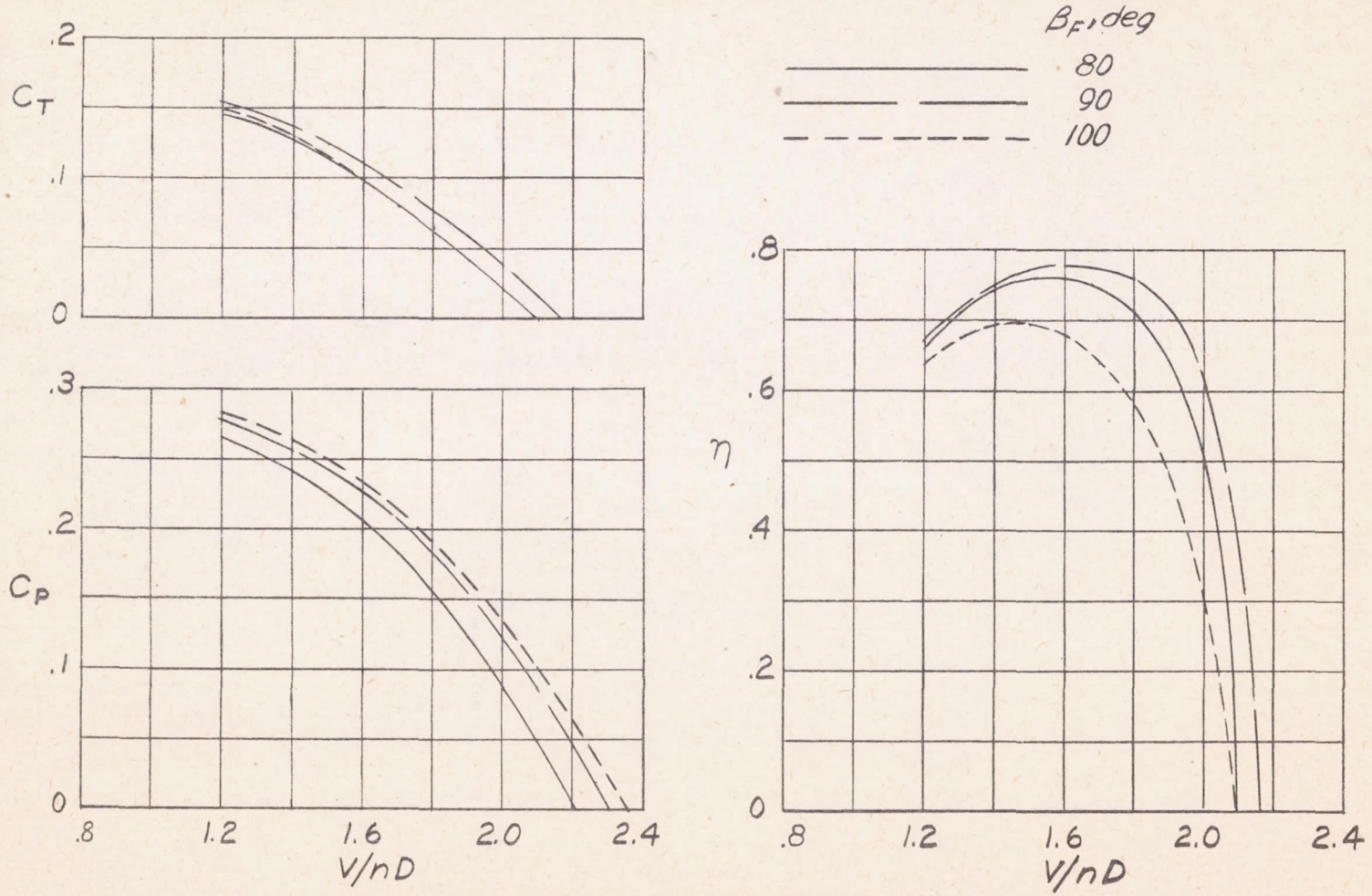
Figure 5.- Continued.

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(c) Pusher propeller; $\beta_F = 40^\circ$; rear propeller locked.

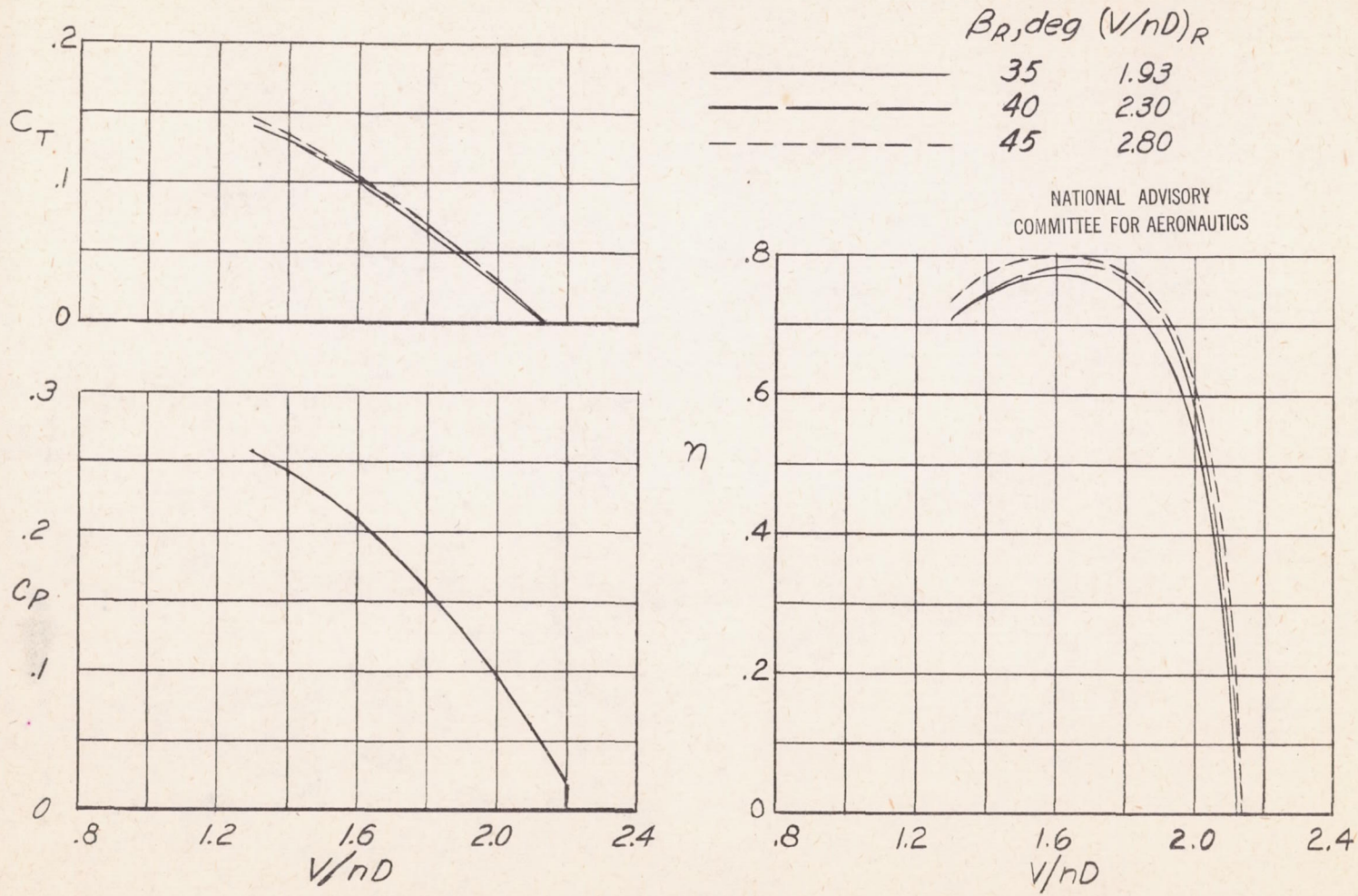
Figure 5.- Continued.



(d) Pusher propeller; $\beta_R = 40^\circ$; front propeller locked.

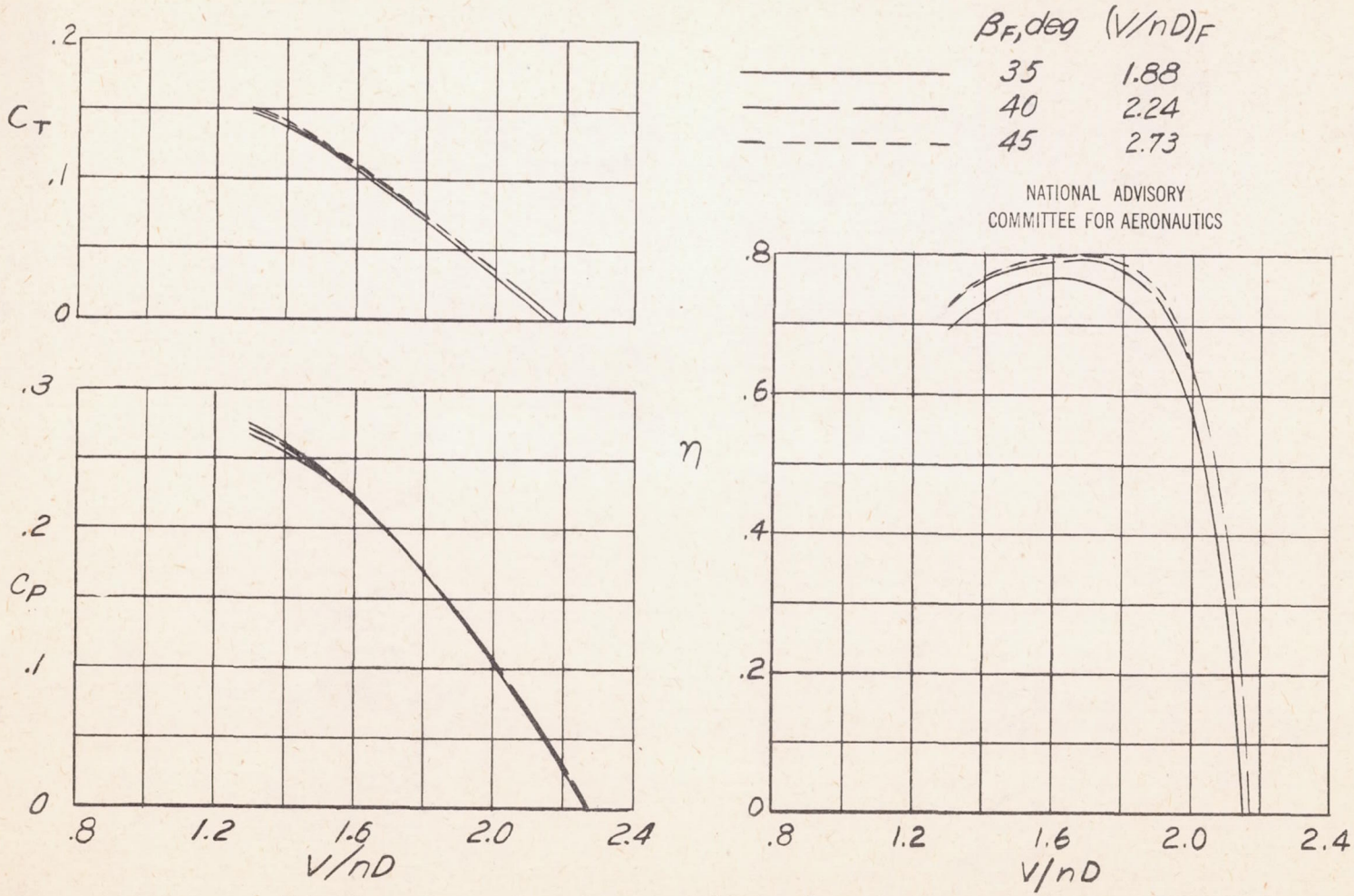
Figure 5.- Concluded.

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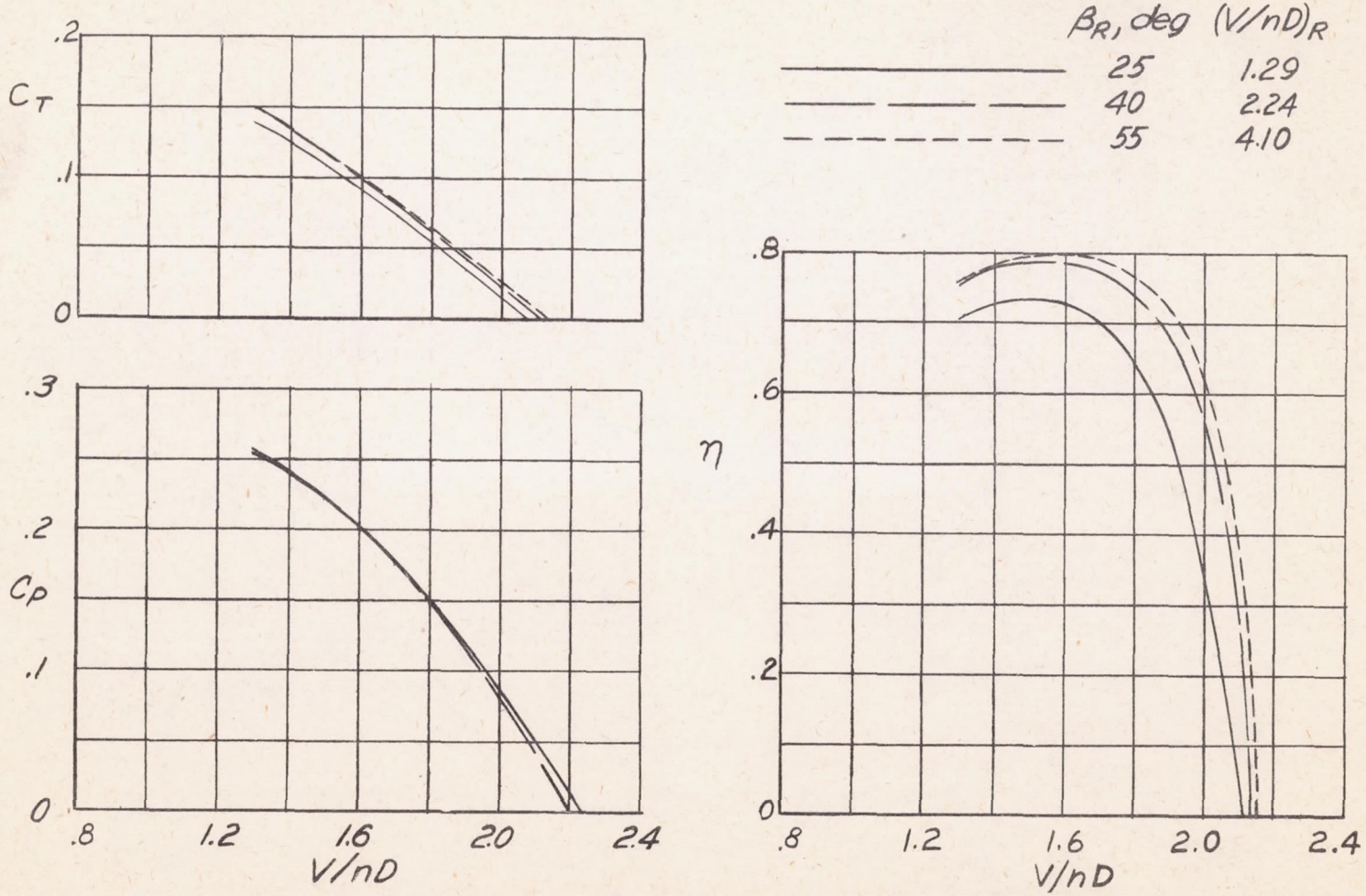
(a) Tractor propeller; $\beta_F = 40°$; rear propeller windmilling.

Figure 6.- Aerodynamic characteristics of the three-blade propeller operating in conjunction with the windmilling propeller.



(b) Tractor propeller; $\beta_R = 40^\circ$; front propeller windmilling.

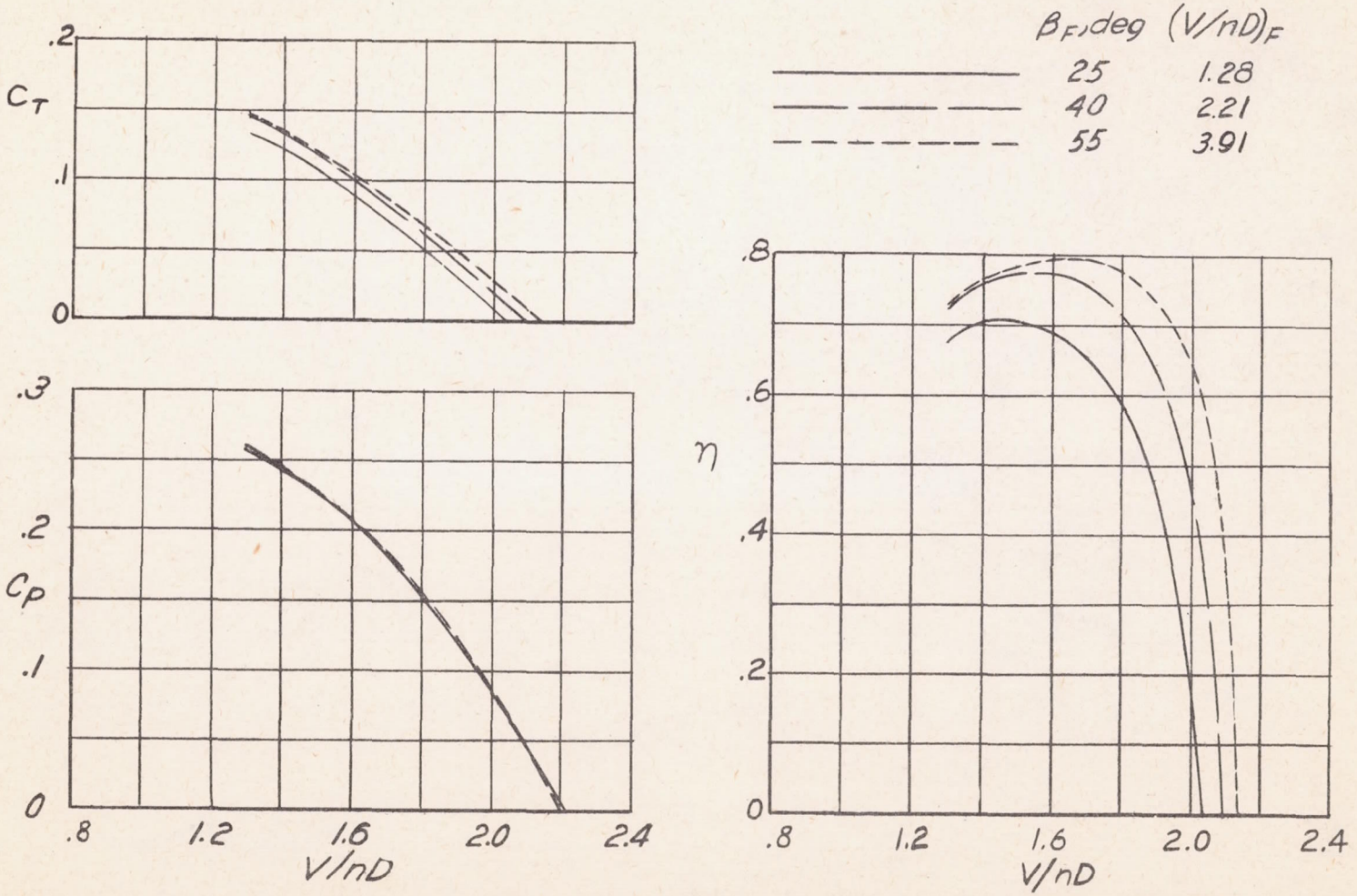
Figure 6.- Continued.



(c) Pusher propeller; $\beta_F = 40^\circ$; rear propeller windmilling.

Figure 6.- Continued.

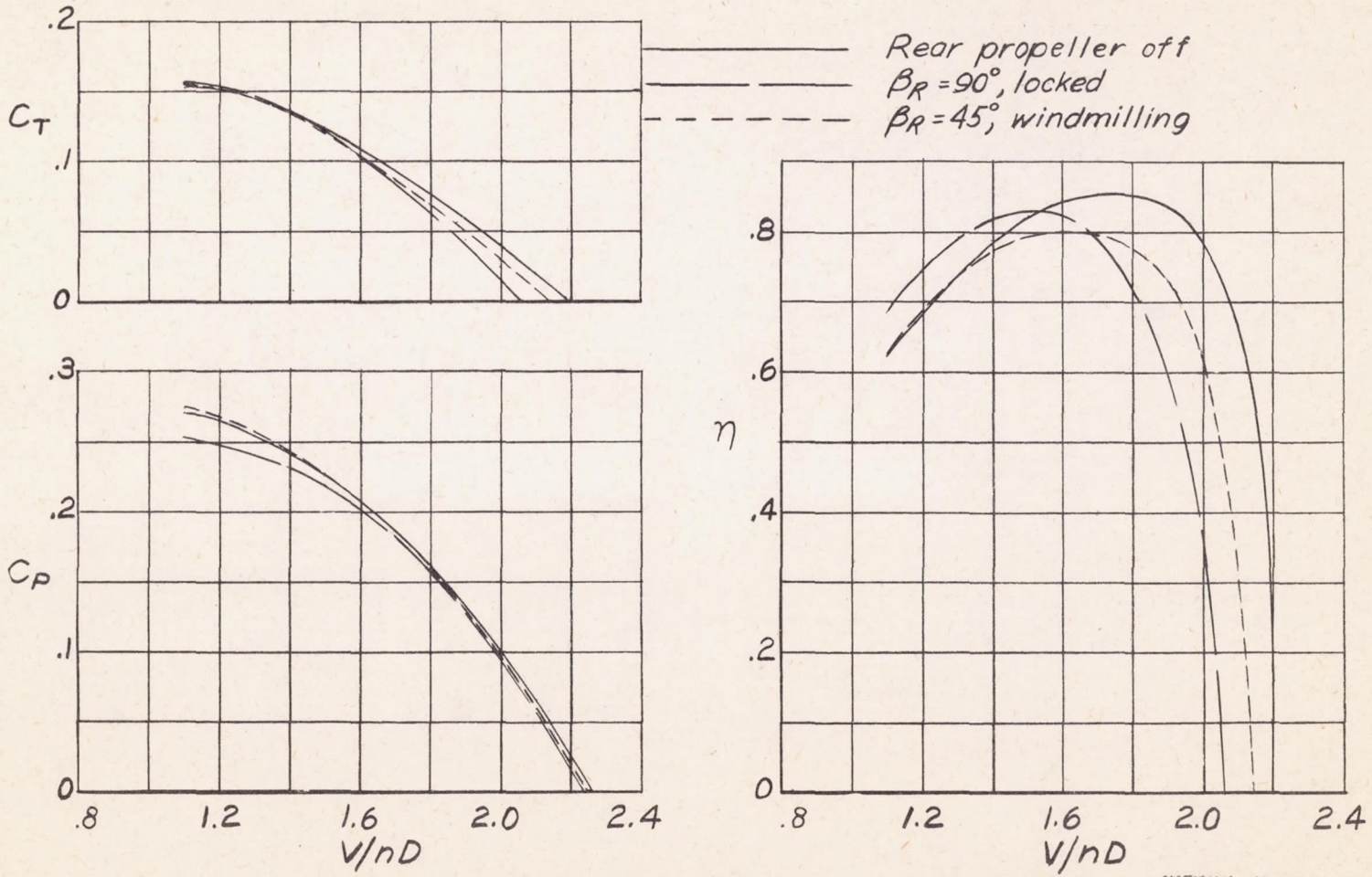
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(d) Pusher propeller; $\beta_R = 40^\circ$; front propeller windmilling.

Figure 6.- Concluded.

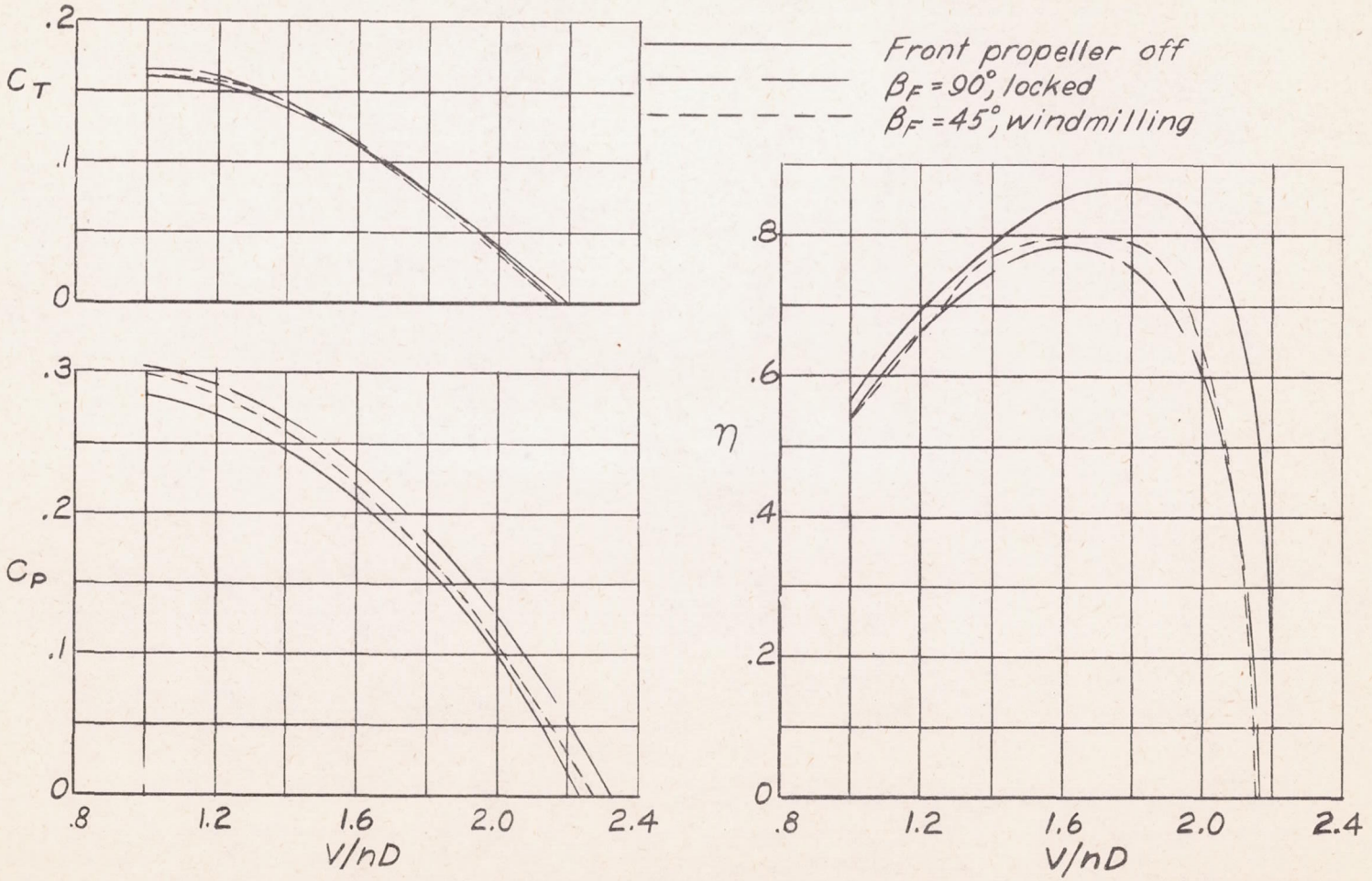
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(a) Tractor propeller; β_F = 40°; front propeller driven.

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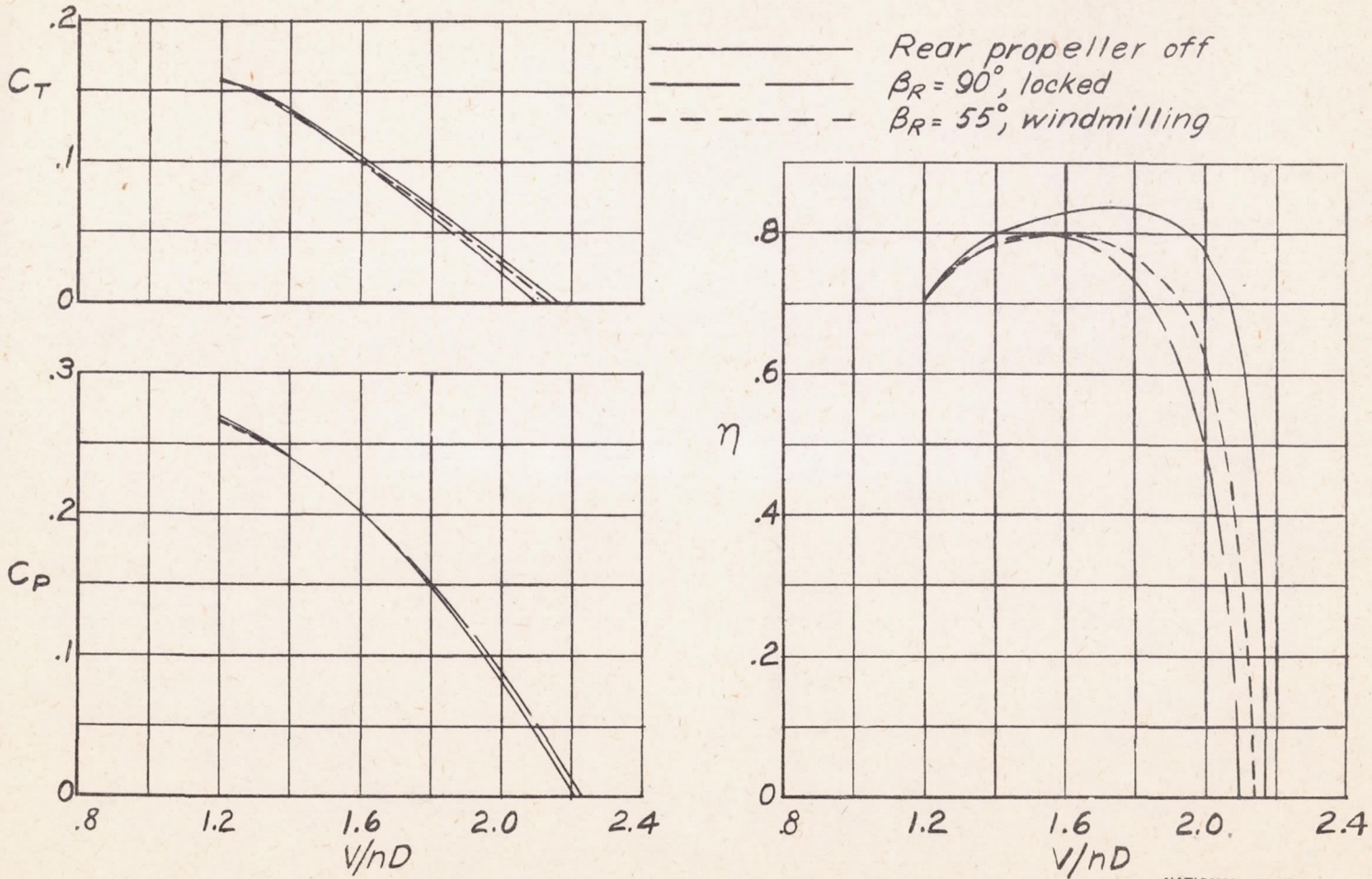
Figure 7.- Comparison of the aerodynamic characteristics of the three-blade propeller operating alone and in optimum combination with the locked or windmilling propeller.



(b) Tractor propeller; $\beta_R = 40°$; rear propeller driven.

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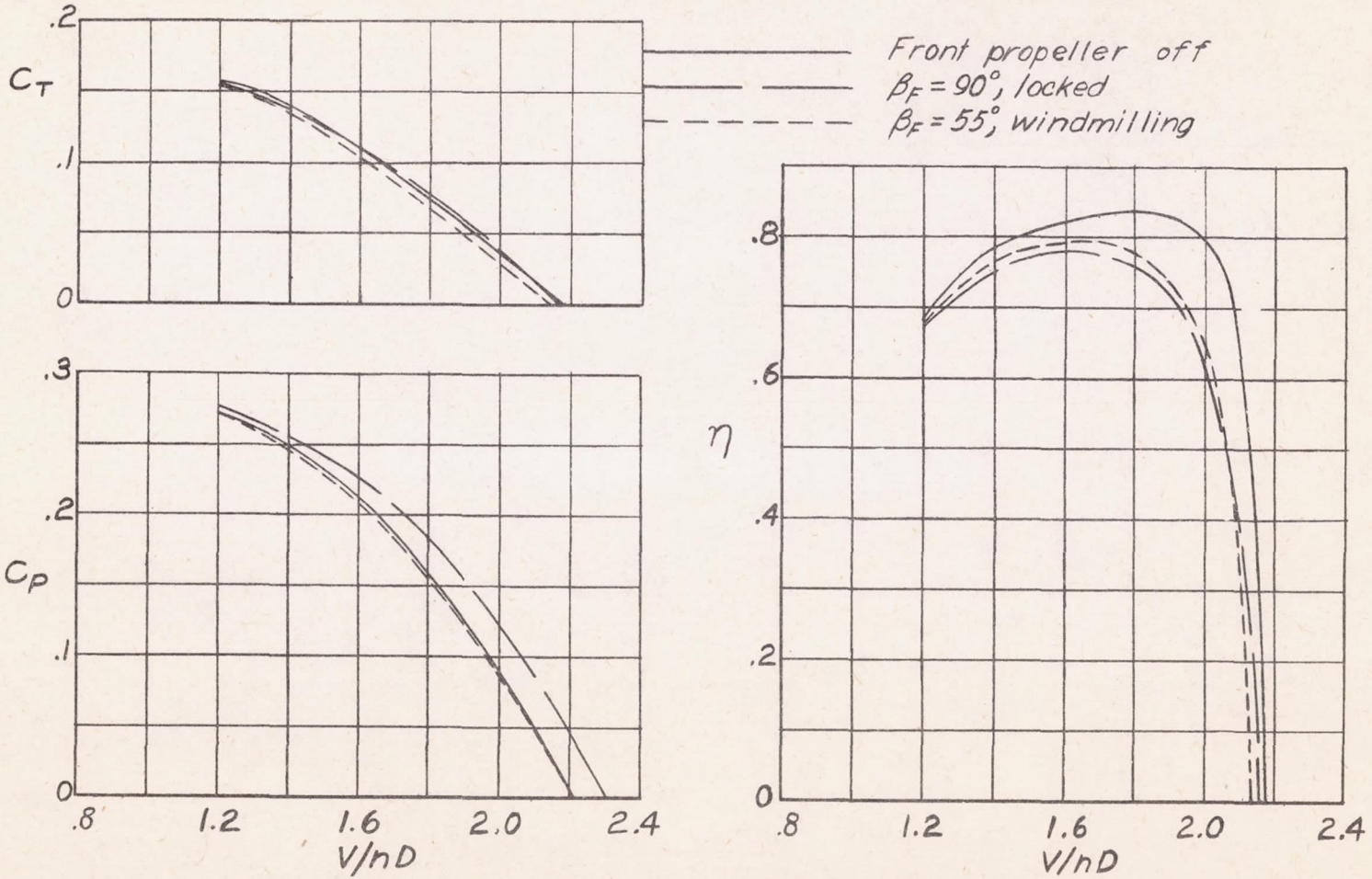
Figure 7.- Continued.



(c) Pusher propeller; β_F = 40°; front propeller driven.

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Figure 7.- Continued.



(d) Pusher propeller; $\beta_R = 40°$; rear propeller driven.

Figure 7.- Concluded.

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